GROUND-WATER MANAGEMENT IN COASTAL GEORGIA AND ADJACENT PARTS OF SOUTH CAROLINA AND FLORIDA: II. NUMERICAL GROUND-WATER MODELING

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Abstract. To assist in the management of coastal ground-water resources, more than 15 numerical ground-water flow and solute-transport models of the Floridan aquifer system have been developed by the U.S. Geological Survey (USGS) and others for all or part of the coastal area of Georgia and adjacent parts of South Carolina and Florida. In general, numerical models of ground-water systems are developed for one or more of the following purposes—(1) to test the feasibility of a conceptual model of the system based on observed hydrologic conditions; (2) to determine the effects of present aquifer uses; or (3) to predict the behavior of the system under hypothetical conditions. Examples of each of these broad categories of numerical models are discussed.

INTRODUCTION

The Floridan aquifer system is the principal source of freshwater in the coastal area of Georgia and adjacent parts of South Carolina and Florida. Water-bearing zones of the Floridan aquifer system were first pumped in the late 1800's and presently yield large quantities of high-quality water for domestic, industrial, and agricultural water supply. Local, regional, and State water management officials use results of ground-water flow and solute-transport models to assist in their efforts to wisely manage the resource, and ensure that there is a sufficient supply of freshwater for present and future uses.

Purpose and Scope

This paper presents examples of numerical ground-water models that have been developed in coastal Georgia and adjacent parts of South Carolina and Florida. Coastal ground-water investigations are driven by a variety of geohydrologic and regulatory issues, and numerical models have been used in these investigations for at least three general purposes—(1) to test the feasibility of a conceptual model of the ground-water system that has been developed based on observed hydrologic conditions; (2) to determine the effects of present demands placed on the aquifer to help formulate management policies; or (3) to predict the probable behavior of the ground-water flow system under various hypothetical pumping scenarios. From the many numerical models developed by the USGS to address particular aspects of coastal ground-water investigations, three are described that illustrate these purposes.

Description of Study Area

The study area includes the coastal area of Georgia and adjacent parts of South Carolina and Florida and is in the Coastal Plain physiographic province. Ground-water use is focused in urban and industrial areas at or near the coast. Urban areas include Hilton Head Island, S.C., Savannah, Ga., Brunswick-St. Simons Island, Ga., St Marys, Ga.-Fernandina Beach, Fla., and Jacksonville, Fla. Major industries include pulp and paper and related industries, tourism, and seafood products.

Geohydrology

The Floridan aquifer system is composed of two principal water-bearing units, the Upper Floridan aquifer and the Lower Floridan aquifer (Krause and Randolph, 1989). Both aquifers are in highly permeable, carbonate sediments of mainly Eocene age. In the Brunswick area, the Upper Floridan aquifer has been divided into the upper and lower water-bearing zones. In the southern part of the coastal area of Georgia and northeastern Florida, the Lower Floridan aquifer includes the Fernandina permeable zone. Throughout the study area, the Upper Floridan aquifer is the preferred source of water supply because of its large yield of high-quality water and also because it is less deeply buried than the Lower Floridan aquifer. Present pumpage from the aquifer system in the Georgia coastal counties, Wayne County, Ga., Beaufort County, S.C., and Nassau County, Fla., is about 320 million gallons per day (Mgal/d) (data on file of Georgia Environmental Protection Division, Atlanta, Ga.).

Background

The following background information on the Floridan aquifer system is summarized from several USGS publications. For a more thorough discussion, refer to Krause and Randolph (1989).

Prior to its development, the Floridan aquifer system was recharged by infiltration in areas southeastward of the Fall Line where it crops out or is near land surface, and ground water was discharged to the Atlantic Ocean in southeastern South Carolina, eastern Georgia, and northeastern Florida. The greater density of seawater relative to freshwater caused a wedge-shaped interface to occur naturally between freshwater and seawater at the discharge boundary of the aquifer system.

Thus, in coastal areas, the interface probably occurred laterally in shallow sediments offshore, and vertically in the lower part of the aquifer system, which includes deeper, saline water-bearing zones.

Since development, large withdrawal has lowered the head in the aquifer system near pumping centers and has reversed the ground-water flow in some coastal areas. On the northern end of Hilton Head Island, S.C., the freshwater-saltwater interface has moved laterally southwestward toward pumping centers on Hilton Head Island and in Savannah, Ga. In Brunswick, Ga., where the freshwater-saltwater interface naturally occurs in the Fernandina permeable zone at a depth of more than 2,000 feet (ft), saltwater has moved vertically upward and is now contaminating formerly freshwater-bearing zones of the Floridan aquifer system as shallow as 500-700 ft. Most of the ground-water management issues in the coastal areas of Georgia, and adjacent parts of South Carolina and Florida, relate to lateral or upward movement of the freshwater-saltwater interface in the Floridan aquifer system.

Previous investigations

Ground-water flow models of the Floridan aquifer system have been developed in the coastal areas of Georgia, and adjacent parts of South Carolina and Florida, by Krause (1982), Krause and Randolph (1989) and Randolph and others (1991); in the Savannah, Ga.-Hilton Head Island, S.C., area by Counts and Krause (1976), Randolph and Krause (1984), Smith (1988), Gawne and Park (1992), Landmeyer (1994), and Garza and Krause (1996); and in the Glynn County (Brunswick), Ga., area by Krause and Counts (1975), Randolph and Krause (1990), and M.L. Maslia and L.E. Jones (U.S. Geological Survey, written commun., 1994). Solute-transport models have been developed in the Brunswick, Ga., area by Bredehoeft and Pinder (1973), and in the Hilton Head Island, S.C., area by Bush (1988) and Smith (1993).

BRUNSWICK FAULT/FRACTURE-ZONE MODEL

In the Brunswick area, chloride-concentration, borehole-geophysical, and other hydrologic data suggest that saltwater is entering the Upper Floridan aquifer from a deeper saline water-bearing zone through breaches in the intervening semiconfining units. Chloride concentration in water samples collected during the drilling of a 2,700-ft-deep well in southern Glynn County in 1978 indicates that the freshwater-saltwater interface occurred at a depth of between 2,140 and 2,320 ft (Gill and Mitchell, 1979). Chloride concentration in water samples collected through time from numerous, areally distributed wells open to the Upper Floridan aquifer (Jones and Maslia, 1994) can be used to illustrate the migration of saltwater contamination from its first appearance in downtown Brunswick in the late 1950's to its eventual withdrawal at pumping centers in northern Brunswick. Characteristic spikes on borehole geophysical logs of gamma radiation taken in numerous wells in the Brunswick area (Jones and Maslia, 1994) define geologic-contact horizons. Offsets in these horizons indicate possible locations of fault or fracture zones (Maslia and Prowell, 1990; Randolph and Krause, 1990). Other hydrologic data that support the possibility of upward migration of saltwater include water-levels, and rates and locations of pumping.

Based on existing hydrologic data from the Brunswick area, the prevailing conceptual model is that saltwater in the lower parts of the Floridan aquifer system is driven by an upward hydraulic gradient between the layered water-bearing zones caused by withdrawal from the uppermost zones (Krause and Randolph, 1989; Maslia and Prowell, 1990). The semiconfining units that separate these zones seem to be breached in isolated locations and allow saltwater, which occurs naturally in the lowest zone, to migrate upward into the normally freshwater zones. The breaches in the confining units may be due to structural weakening at stratigraphic offsets caused by faulting and/or fracturing. The migrating water probably has dissolved cavities in the carbonate rocks, which allows greater flow between the water-bearing zones.

To test the feasibility of this conceptual model, M.L. Maslia and L.E. Jones (U.S. Geological Survey, written commun., 1994) used the USGS model, MODFE (Torak, 1992a,b; Cooley, 1992), to simulate ground-water flow in the upper water-bearing zone of the Upper Floridan aquifer. MODFE, which solves the ground-water flow equations using finite-element techniques, allowed the locations of linear fault and fracture zones to be incorporated in irregular, triangular elements. Thus, the upward flow of water through planar fault/fracture zones into the upper water-bearing zone of the Upper Floridan aquifer could be simulated.

Calibration of the model was achieved by comparison of simulated and measured water levels for steady-state conditions and by comparison of simulated and measured drawdown through time during an industrial pumpage shutdown for transient conditions. With acceptable accuracy, the calibrated model was used to simulate historical hydrologic conditions during periods of near steady pumpage and drawdown at observation wells during aquifer tests.

HILTON HEAD ISLAND CAPTURE-ZONE MODELS

Landmeyer (1994) used analytical and numerical ground-water flow modeling of the Upper Floridan aquifer to delineate contributing areas or capture zones around public-supply wells on Hilton Head Island, S.C., based on present pumping rates. This assessment, which is required under the Wellhead Protection Program of the Safe Drinking Water Act (U.S. Environmental Protection Agency, 1987), was conducted by the USGS in cooperation with the South Carolina Department of Health and Environmental Control to determine the effectiveness of various capture-zone delineation techniques for pumped wells in major drinking-water aquifers in South Carolina.

Landmeyer (1994) used three analytical models and two numerical models to determine capture zones for ten pumped wells located from central to southwestern parts of Hilton Head Island. The analytical models are of the fixed-radius type and use the equations of radial ground-water flow to a pumped well. For each analytical model, one variable was solved based on the specification of another—the arbitrary fixed-radius model was used to determine a travel time for a specified radial distance; the calculated fixed-radius model gave a radial distance for a specified travel time; and the Theis model yielded a radial distance for a specified threshold value of drawdown. The numerical models are based on ground-water flow equations solved using finite-difference techniques by the computer codes, RESSQC and MWCAP (Blandford and Huyakorn, 1990). Using simulated ground-water flow rates, capture zones for the pumping wells were estimated for various travel times. Both numerical models account for the regional flow system, and the RESSQC model accounts for multiple-well interference.

Numerical model results were compared to analytical model results, and it was demonstrated that the two numerical models provided the most realistic and accurate capture-zone delineation. However, the numerical models required substantially greater technical expertise to implement.

TELESCOPING REGIONAL AND SUB-REGIONAL MODELS

The USGS has developed a telescoping approach (Garza and West, 1995) to link sub-regional models in the Savannah, Ga.–Hilton Head Island, S.C., area (Garza and Krause, 1996) and the Glynn County, Ga., area (Randolph and Krause, 1990) to a larger regional model covering the entire coastal area (Krause and Randolph, 1989). The telescoping, digital models all use the USGS computer code, MODFLOW (McDonald and Harbaugh, 1988), which solves the ground-water flow equations using finite-difference techniques. By applying hypothetical pumping-change scenarios anywhere in the coastal area, the telescoping models can be used to predict detailed hydrologic conditions in local areas. This type of predictive modeling is being increasingly employed by water-resources managers to assess various ground-water- management plans.

The telescoping approach of Garza and West (1995) facilitates data transfer to, between, and from the regional and sub-regional models. Preprocessing routines allow specification of hypothetical pumping changes, which are incorporated into the calibrated input data for each of the models. By first executing the regional model, ground-water flow rates at the lateral boundaries of the sub-regional models are computed and applied in subsequent executions of the sub-regional models. Within the areas of the sub-regional model grids, the simulated flow system of the sub-regional model is equivalent to the flow system simulated by the regional model, but the sub-regional model provides more detail of the flow system on a local scale. Postprocessing routines compute drawdown as the difference between water levels simulated for the calibrated pumping rates and those simulated by incorporating the hypothetical pumping changes.

The predictive capability of the telescoping models is illustrated by determining the development potential of the aquifer limited by a specified drawdown at particular locations. In this example, a maximum drawdown of 0.05 ft was specified for two locations using indicator grid cells: one at the northern end of Hilton Head Island, S.C., in the Savannah, Ga.-Hilton Head Island, S.C., area model, where the freshwater-saltwater interface has migrated laterally; and the other in downtown Brunswick, Ga., in the Glynn County, Ga., area model, where saltwater has moved vertically upward through semiconfining units. Multiple telescoping-model simulations were performed by applying a 10 Mgal/d pumping change at each point in a 16-mile grid over the study area. Using the drawdown computed at the two indicator cells for each simulation, the pumping rate that would cause the 0.05-ft drawdown was determined for each pumped location, based on the drawdown resulting from the 10 Mgal/d pumping change. Contouring these pumpage quantities produces lines of equivalent development potential of the Upper Floridan aquifer in the coastal area subject to the specified drawdown at the indicator locations. Water-resources managers can use this information to assess trade-offs between pumping rates at various locations, with respect to drawdown at these two sensitive locations.

CONCLUSION

In the coastal area of Georgia and adjacent parts of South Carolina and Florida, the Floridan aquifer system is an invaluable source of freshwater, which is beset by myriad complex issues of concern to water managers in each of the three States. Different types of numerical models have been used in a variety of ways to provide information about the nature, behavior, and future management of the aquifer system. Continuing a trend that has developed through more than two decades of water-resources investigations in the area, numerical ground-water modeling has been and will be used as an objective, scientific tool to assist water-resources managers in wisely managing the increasing demands on the resource and ensuring that the Floridan aquifer system remains a source of freshwater for future uses.

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